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The Control of Water on the Pre-Eruptive Depth of Arc Magmas

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Despite the clear requirement that magma must ascend from the mantle to the volcano within a trans-crustal magmatic system, geophysical studies commonly find evidence for discrete regions of magma accumulation that are vertically restricted to a few km. These pre-eruptive storage regions may vary in depth from 1 to 15 km. What processes lead to these depths of magma storage? Prevailing notions include neutral buoyancy and magma viscosity. We show that the depths of magma storage for 168 volcanoes (6 +/- 3 km), however, are greater than depths of neutral buoyancy (generally < 3 km). On the other hand, the water content of mafic-to-intermediate arc magmas, as determined by melt inclusion measurements, increase as the geophysically determined depth of magma storage increases. Not only is there a strong water–depth trend, but the trend coincides with the water-saturation curve. This provides strong evidence for a link between observed water content and depth. For half of the studied systems, this is the only known region of magma storage. For the other half, two or more discrete regions of magma storage have been identified. Two plausible explanations exist for the water-depth relationship: (i) Magmatic water contents control magma stalling, or (ii) the storage depth of magmas dictates the water contents of the melt inclusions. If the latter is true, however, we would expect diffusive re-equilibration of water to destroy any relationship between water and non-volatile slab tracers (e.g., Nb/Ce), and yet such relationships have been noted for several arcs, including in our new data for the Aleutians. We thus explore the physical control of water on magma viscosity using rhyolite-MELTS. Magma viscosity increases strongly when magmas reach water saturation, as the loss of water to vapor both increases melt viscosity and drives crystallization. Intrinsically wetter magmas degas water and crystallize deeper than drier magmas, resulting in viscosity increases that lead to deeper stalling of ascending magma. Our results demonstrate that magmas are buoyant at their storage depth, providing a driving force for ascent and eruption. [1]

[1] Rasmussen et al., 2022, Science.